Effect of Roof Load on Substantial Dividing Wall (SDW) Protection

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Abstract

The Naval Facilities Engineering Service Center (NAVFAC ESC) was tasked by the U.S. Department of Defense Explosive Safety Board (DDESB) to evaluate the effect of roof load on the protection provided by substantial dividing walls (SDW). The latest DDESB Substantial Dividing Wall (SDW) guidance memo (January 2003) allows the placement of up to 425 pounds of Sensitivity Group (SG) 1 through SG 4 explosives in a partial containment bay for siting purposes. The application of this SDW guidance includes a weight limit of 10 psf for all frangible surfaces. If one of the frangible surfaces is a roof, the memo requires consideration of the site specific snow load in calculating the roof's weight.

In many areas of the U.S. the snow load is too high to allow the roof to be considered a frangible surface. In other areas, snow may not be present, but the actual roof weight may exceed 10 psf anyway. As a result, the SDW memo often cannot be applied and the SDWs must be analyzed according to criteria developed for the U.S. Navy High Performance Magazine Non-Propagation Wall. The resulting net explosive weight (NEW) limits are often too low to satisfy minimum operational requirements for preventing propagation of detonation.

This paper examines the effect of additional roof loading using three storage facilities (described in Section 3.0) as examples. Roof loads between 10 psf and 40 psf are examined as well as charge weights up to 425 pounds.

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14. ABSTRACT

The Naval Facilities Engineering Service Center (NAVFAC ESC) was tasked by the U.S. Department of Defense Explosive Safety Board (DDESB) to evaluate the effect of roof load on the protection provided by substantial dividing walls (SDW). The latest DDESB Substantial Dividing Wall (SDW) guidance memo (January 2003) allows the placement of up to 425 pounds of Sensitivity Group (SG) 1 through SG 4 explosives in a partial containment bay for siting purposes. The application of this SDW guidance includes a weight limit of 10 psf for all frangible surfaces. If one of the frangible surfaces is a roof, the memo requires consideration of the site specific snow load in calculating the roof’s weight. In many areas of the U.S. the snow load is too high to allow the roof to be considered a frangible surface. In other areas, snow may not be present, but the actual roof weight may exceed 10 psf anyway. As a result, the SDW memo often cannot be applied and the SDWs must be analyzed according to criteria developed for the U.S. Navy High Performance Magazine Non-Propagation Wall. The resulting net explosive weight (NEW) limits are often too low to satisfy minimum operational requirements for preventing propagation of detonation. This paper examines the effect of additional roof loading using three storage facilities (described in Section 3.0) as examples. Roof loads between 10 psf and 40 psf are examined as well as charge weights up to 425 pounds.

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1.0 INTRODUCTION

1.1 BACKGROUND

DOD explosives safety standards allow the use of substantial dividing walls (SDWs) in explosives research and development facilities, munitions plants, ammunition maintenance and inspection facilities, and storage magazines (Ref. 1). SDWs may be used to divide quantities of ammunition among the operating bays so that an accidental detonation in a single operating bay will not cause the prompt sympathetic detonation (SD) of ammunition in any exposed operating bays.

To qualify as SDWs, walls separating operating bays must satisfy the following characteristics:

a) A minimum thickness of 12 inches
b) Steel reinforcing bars (rebar) on both faces of the wall
c) # 4 (½-inch in diameter) vertical and horizontal rebar
d) Vertical and horizontal rebar spaced not more than 12 inches apart
e) Position of bars on one face staggered with the bars on the opposite face
f) Two inches of concrete cover over the reinforcing bars
g) Minimum concrete compressive strength of 2,500 psi

The Air Force and Army standards have permitted siting on the basis of the largest quantity in a single group, when groups are divided by a 12-inch SDW, when the largest Net Explosive Weight (NEW) in a single group does not exceed 425 pounds, and when the explosives are not closer to the SDW than 3 feet (Refs. 2 and 3). Explosives testing has shown that a 12-inch SDW will prevent sympathetic detonation (SD) of ammunition in Sensitivity Groups 1 through 4 (SG1 through SG4) (Ref. 5).

In January 2003, the Department of Defense Explosives Safety Board issued interim guidance in the use of SDWs to prevent propagation of detonation (Ref. 6) between bays. The interim guidance states that each bay containing HE (to include any HD 1.3 contributions) shall be limited to a Maximum Credible Event (MCE) of no more than 425 pounds explosive weight of Sensitivity Groups (SG) 1, 2, 3 and/or 4 munitions. Test data does not currently support the use of a 12-inch thick SDW to prevent simultaneous detonation of SG5 munitions. Therefore, when establishing the MCE, the explosive weight of all munitions in any bay containing SG5 munitions must be combined with the MCE for any adjacent bays that contain greater than 8 pounds of HD 1.1 explosive.

In addition to the physical characteristics of the SDWs, the DDESB guidance places limits on size and location of the explosive donor, and states requirements for venting of blast pressures from a cubicle. These requirements may be summarized in the following:

(1) The Maximum Credible Event (MCE) is limited to 425 lbs. Net Explosive Weight (NEW).

(2) The minimum separation distance from any wall to any explosive donor is 3-feet.

(3) The loading density (Net Explosive Weight/ room's internal volume) shall be less than 0.20 lb/ft^3 for Sensitivity Groups (SGs) 1 through 4. For SG5, the loading density cannot exceed 0.01 lb/ft^3.

(4) The minimum scaled vent area ($A/V^{2/3}$) for the cubicle is 1.85. A is defined as the total uncovered and covered area for venting blast pressures. V is defined as the internal volume of the cubicle.

(5) The maximum unit weight of any frangible surface (such as the roof and a wall) is 10 lb/ft^2.

The guidance provided by the DDESB is based on explosives tests conducted in September and November 2001. The results of these tests are documented in References 2 and 3.

Reference 5 documents the development of the SD criteria, the method for classifying munitions into the five sensitivity groups, and the method for designing composite non-propagation walls. SD thresholds have been established for each of the five sensitivity groups. These thresholds limit the applied unit impulse and energy loads on acceptor ordnance in order to prevent SD. In the design of a SDW, the calculated unit impulse load, the unit kinetic energy of the SDW, and the SDW velocity must be less than or equal to the threshold limits of the acceptor ordnance.

The requirement that the maximum unit weight of any frangible panel, including the roof, have a unit weight less than or equal to 10 lb/ft^2 often cannot be met when a snow load is added to the roof. This paper examines the effect of additional roof loading using three storage facilities (described in Section 3.0) as examples.

1.2 GENERAL PROCEDURE DESCRIPTION

The procedure outlined in this paper is a combination of steps to determine the effect of an increased roof load on the effectiveness of SDWs. The key steps involve the use of computer codes for predicating internal loads and evaluation of Sensitivity Group (SG) thresholds. The procedure includes loading prediction on internal surfaces, determination of breaching for SDW surfaces, and calculations of munitions response from SG thresholds.

The general description of each of these steps is given in this section. More explicit steps are provided in section 2.1.

1.2.1 Loading Prediction on Internal Surfaces

The first step in the procedure is to define the threat in terms of the charge amount and location and the wall and roof components of the structure. Once the explosive threat and building characteristics have been established, the second step of the model is to determine internal loads on each component. Blast loading inside a confined space can be characterized by an initial shock phase which is usually followed by a gas or quasistatic phase loading. The shock phase consists of very short duration, high pressure pulses which load surfaces as the shock reverberates within the bay. The magnitude of the shock phase depends on the charge amount, the distance to the loaded surface, and the location of nearby reflecting surfaces. The magnitude and duration of the quasistatic phase depend on the charge amount, the bay volume, and the available vent area and mass of vent covers

The SHOCK and FRANG computer codes are used to determine the shock and gas impulse on all components in the donor structure. A combination of the impulse predicted using both codes is used to calculate the response of the SDW.

1.2.2 Breaching Prediction of SDW

Direct spalling and breaching of SDW are due to a compression wave traveling through a concrete element, reaching the back face and being reflected as a tension wave. Spalling, and eventually breaching, occurs when the tension is greater than the tensile strength of the concrete. The breach threshold curve defined in UFC 3-340-02 section 4-55 provide the wall thickness at which breaching will occur. The controlling parameters include distance from the charge to the surface, concrete compressive strength, and charge weight.

1.2.3 Munitions Response to Impact from SDW

As part of the High Performance (HP) magazine program, all DOD ordnance has been reviewed and classified into one of five sensitivity groups (SG1 through SG5). Sensitivity Groups are used to classify ordnance by its sensitivity to crushing by secondary debris from non-propagation walls (NPWs). Reference 6 details how the DOD ordnance was classified into the five SGs and describes the certification tests for non-propagation walls in the Navy HP magazine.

Per Paragraph C3.2.3 of Reference 1, each HD 1.1 and HD 1.2 ordnance item located in an ordnance facility where SDWs are used to reduce to the maximum credible event, must be assigned to one of the five SGs:

(1) SG1: Robust Munitions
(2) SG2: Non-Robust Munitions
(3) SG3: Fragmenting Munitions
(4) SG4: Cluster Bombs/Dispenser Munitions
(5) SG5: SD Sensitive Munitions

Table 1-1 lists the thresholds for unit impulse and kinetic energy loads which may be applied to acceptors from the five sensitivity groups (Ref. 5). If the calculated momentum and kinetic energy of the secondary debris from SDWs are less than the thresholds, detonation of ordnance due to crushing is not expected.

Table1-1. Summary of SD Threshold Criteria for Sensitivity Groups

HP Magazine Sensitivity Groups		Unit Impulse and Energy Loads	
Group No.	Group Description	Impulse, I_{thres} (psi-sec)	Energy, KE_{thres} (ft-k/in^2)
1	Robust	45	24.5
2	Non-Robust	67	24.5
3	Fragmenting	53	8.49
4	Cluster Bombs/ Dispenser Munitions	25.6	3.77
5	SD Sensitive	5.23	0.3

2.0 GUIDELINES FOR USING THE PROCEDURE

The criteria for SDWs to prevent SD are provided in this section. The procedure presented in this section defines the following steps for analyzing SDWs:

1) Define the architectural layout of the facility. The architectural layout will show the location of explosive materials and the location of neighboring bays.
2) Define hazard scenarios resulting in the propagation of detonation between groups of explosive materials. The hazard scenarios define locations of donor and acceptor groups, hazard mechanisms, and methods of mitigating the hazard mechanisms. Acceptor and donor groups include all groups of munitions located in a facility.
3) Calculate the shock loads applied to the SDWs.
4) Determine acceptor munitions response to debris impact from SDWs. This method determines the effective loads on acceptor munitions and establishes the MCE for all donor groups of munitions in the open storage module.

2.1 LOAD ENVIRONMENT FOR THE SDW

The SDWs separating groups of munitions must reduce the environment at the acceptor to below threshold levels for sympathetic detonation (SD). SD is highly dependent on the blast load environment (and other mass and material characteristics of the SDW). This section describes the methods employed for determining the magnitude of the dynamic blast load environment on the SDWs.

For confined explosions inside a facility, the worst-case load environment on the SDW, includes: (1) the initial shock loads, and (2) the long duration, quasi-static loads due to containment of the explosive by-products in the operating bay.

The following procedure is used to determine the load on the SDW.

2.1.1 Determine the location and size of the explosive donor.

The critical variables for determining the shock loads are: (1) the total donor explosive weight, and (2) the location of the explosives within the operating bay.

2.1.2 Determine the shock load on the SDW.

Initial shock loads are calculated using the computer program SHOCK. SHOCK (Ref. 4) calculates the shock pressure and impulse on the SDW, bounded by four reflecting surfaces, including the floor, two adjacent walls and ceiling.

SHOCK has the ability to calculate the shock load at any point on the loaded surface. This ability is used to calculate loads at all grid points on the SDW. The critical parameters for defining the locations of a donor charge, with respect to the loaded surface, are summarized in the following (Figure 2-1):

H – height of the loaded surface (ft)
L – length of the loaded surface (ft)
l - horizontal distance from the lower left corner of the SDW to the center of gravity of the donor charge (ft)

h – vertical distance to the center of gravity of the donor charge (ft)
R_A - separation distance from the loaded surface to the donor charge (ft)
N – number of reflecting surfaces

For calculating the design shock load on a grid point, the following two parameters are required:

x_P – horizontal distance from the lower left corner of the loaded surface (ft)
y_P - vertical distance from the lower left corner of the loaded surface (ft)

For each SHOCK calculation, a grid of points is defined for the surface of the SDW. Each grid point is defined by x and y coordinates (where x is measured along the length of the loaded surface, and y is measured along the height of the loaded surface).

SHOCK will calculate impulse, pressure and duration of a triangular load for each grid point on the surface of the LDW.

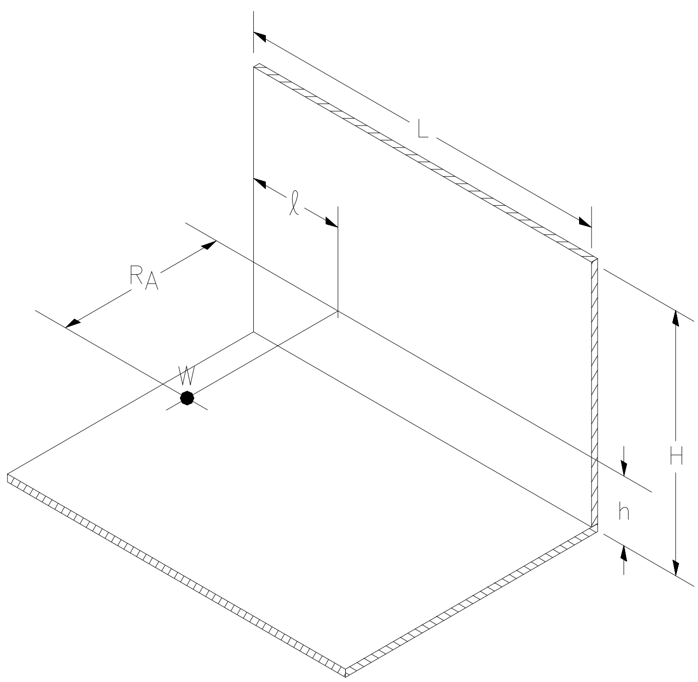

Figure 2-1. Location of NEW.

2.1.3 Determine the Gas Pressure Load.

This step is applied to confined explosions inside a facility, the worst-case load environment on the SDW, which include the long duration, quasi-static loads due to containment of the explosive by-products in the facility.

The computer program, FRANG 2.0 (Ref. 7), calculates the gas pressure history as explosive gases vent through openings and multiple frangible panels. Determining the total gas load acting on the walls requires a FRANG calculation for the gas impulse with pressure venting through any covered and uncovered openings.

The gas impulse loads on the SDW are dependent on the total explosive weight in the bay, and the size and shape of the doors and roof. The critical variables for determining the gas impulse loads include: (1) the total donor explosive weight, (2) the shock impulses calculated for all frangible surfaces, (3) size and weight of the frangible surfaces.

2.1.4 Determine SDW Load by Combining Shock and Gas Impulses.

For each NEW, the shock and gas impulses are summed at each grid point to obtain the total impulse. The grid points on an SDW are grouped into reduced areas. A reduced area is defined as nine adjacent grid points for shock impulses that have been calculated. See Figure 2-2. For each reduced area, the design impulse load (I_D) is calculated. The design impulse load, I_D, is the average of the impulses for the nine grid points in the reduced area.

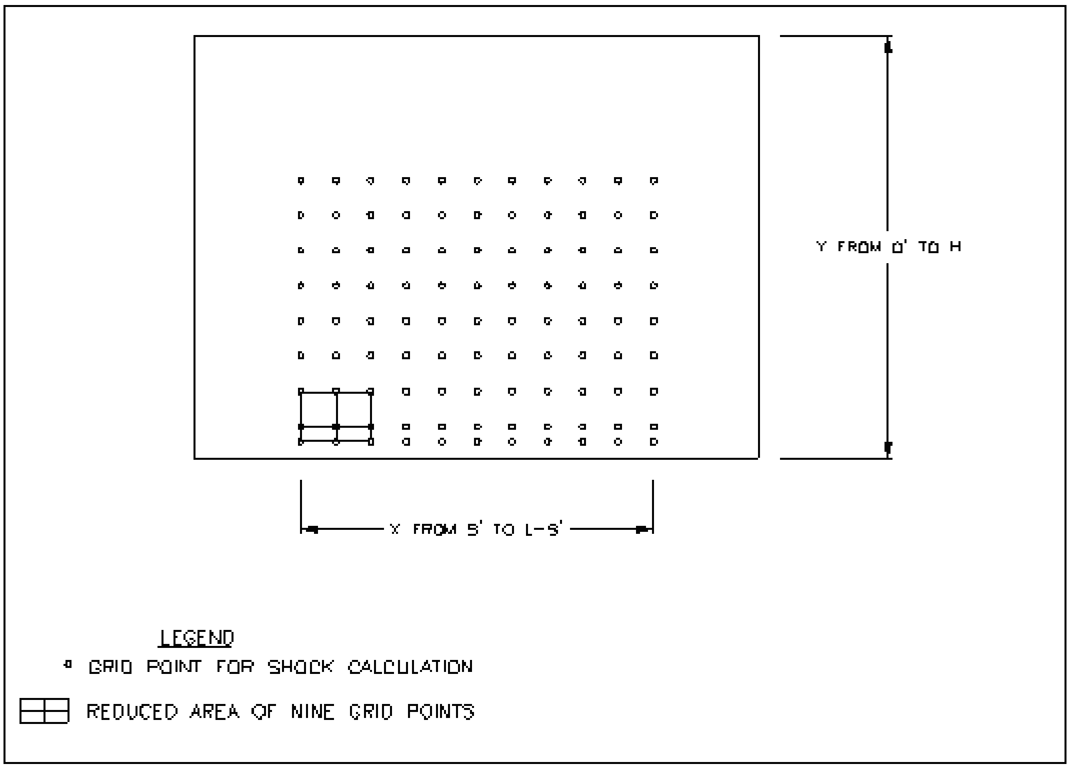

Figure 2-2. Typical reduced area of nine grid points on a LDW.

2.2 MUNITIONS RESPONSE TO IMPACT FROM SDW DEBRIS

This section compares the SD criteria with the calculated load environment on acceptor ordnance. These criteria prevent SD of the acceptor ordnance by mitigating crushing and rupturing of the acceptor during debris impact. The criterion limits the unit kinetic energy and momentum of debris, which may crush and rupture an acceptor.

2.2.1 Sympathetic Detonation Criteria.

Flyer plate impact tests have been completed on critical acceptors for the five SGs. SD threshold criteria limiting the unit impulse and energy loads on acceptor ordnance has been developed from these tests. Table 1-1 summarizes the developed SD threshold criteria.

SG5 contains very sensitive ordnance items and those with unknown sensitivity that cannot be classified, by test or analogy, into the other four groups. A SG5 ordnance item can be classified into another group if testing or analysis has determined the applicable SD threshold group.

2.2.2 Breaching of SDW Surfaces.

It is necessary to determine if breaching of the SDW occurs. If breaching occurs the unit impulse and energy of the resulting debris is used to evaluate if SD occurs. If breaching does not occur, the average wall impulse is used to calculate the wall velocity. The breach threshold curve defined in UFC 3-340-02 section 4-55 provides the wall thickness at which breaching will occur. The controlling parameters include distance from the charge to the surface, concrete compressive strength, and charge weight. Equation 2-1 is used to calculate breach thickness, h.

$$\frac{h}{R} = \frac{1}{a + b\psi + c\psi^2} \qquad \textbf{Eq. 2-1}$$

Where:

h	=	concrete thickness (ft).
R	=	range from slab face to charge center of gravity (ft).
a	=	0.028205
b	=	0.144308

$$\psi = R^{0.926} f_c'^{0.266} W_{adj}^{-0.353} \left(\frac{W_{adj}}{W_{adj} + W_c} \right)^{0.333} \qquad \textbf{Eq. 2-2}$$

Where:

ψ	=	spall parameter
W_{adj}	=	adjusted charge weight (lb)
W_c	=	steel casing weight (lb)

If the calculated breaching threshold thickness (h) is less than the thickness of the SDW breaching will not occur. In these situations the calculated wall velocity must be less than 60 ft/s to prevent SD.

2.2.3 SDW Load Environment vs. SD Criteria.

The criteria for SDWs are based on test data from a single explosives test. This test shows that a SDW will prevent SD of ordnance from SGs 1 through 4.

Since the SD criteria loads are based on flyer plate test data, the calculated SDW impulse loads must be converted to equivalent flyer plate loads to properly apply the SD criteria. A conversion factor, also known as impulse equivalency ratio, F, is multiplied with I_D to obtain I_{efp}. Equation 2-3 is used to calculate I_{efp}.

$$I_{efp} = F\ I \qquad \textbf{Eq. 2-3}$$

Where:

I	=	the calculated impulse, I_D.
F	=	1.0, This value is applicable to reinforced concrete walls based on results of the substantial dividing wall test.

The unit energy of the wall debris is determined in Equation 2-4:

$$KE_{efp} = 2.32\ (I_{efp})^2\ /m_{wall}\ (\text{ft-k/in}^2) \qquad \textbf{Eq. 2-4}$$

Where:

I_{efp}	=	equivalent flyer plate impulse load determined from Eq. 2-3, in psi-sec
m_{wall}	=	unit weight of the SDW, in lb/ft^2

A wall velocity limit threshold shall be applied to SDWs where breaching does not occur. The velocity limit thresholds for SDW are based on the average wall impulse load, and is limited to 60 feet-per-second.

The velocity of the SDW debris is determined in Equation 2-5:

$$V_{SDW} = 4640\ I_{avg}\ /m_{wall}\ \ (\text{feet-per-second}) \qquad \textbf{Eq. 2-5}$$

Where:

I_{avg}	=	The average wall impulse load from Section 2.1.4, in psi-sec.
m_{wall}	=	unit weight of the SDW, in lb/ft^2

Using the various values of I_D and m_{wall}, the effective loads (I_{efp} and KE_{efp}) are tabulated. I_{efp} and KE_{efp} are equal to the impulse and energy loads. V_{SDW} is based on the wall velocity calculated for the wall average impulse load.

3.0 RESULTS

In this section three facilities are evaluated; Anniston Ammunition Depot Building 381 Missile Recycling Complex (MRC), Holloman AFB multi-cube, and Whiteman AFB multi-cube. These facilities were chosen as representative of common SDW designs. The result of increased roof load is illustrated for each facility in the following sections.

3.1 ANNISTON AMMUNITION DEPOT BUILDING 381 MISSILE RECYCLING COMPLEX (MRC)

3.1.1 Facility Description

Figures 3-1 and 3-2 show the layout of Building 381. As shown in Figure 3-1, Building 381 is subdivided in 21 bays, labeled A through U; four additional bays labeled 1 through 4 are detached from the main building. For Bays A through U, the outer walls of the building are frangible, while the internal walls are SDWs. Bays B, T and A are separated from Bay U by SDWs.

Figure 3-2 shows a detailed layout with dimensions for Bay U. The walls of Bay U are composed of two SDWs and two frangible cinder block walls. The dimension of Bay U is 41.5-feet long x 24.5-feet wide x 13.67-feet high. The SDWs are 12-inches thick and have a weight of 150 lbs/ft^2. The cinder block walls are 8-inches thick and are composed of hollow 8-inch x 8-inch x 16-inch cinder concrete blocks. The weight of the blocks is conservatively rounded up to 50-lbs/ ft^2 in the analysis. The roof weighs 12.6-lbs/ ft^2 and is composed of 1-inch gravel, 5-ply roof felt, steel decking and 4.5-inches of perlite insulation.

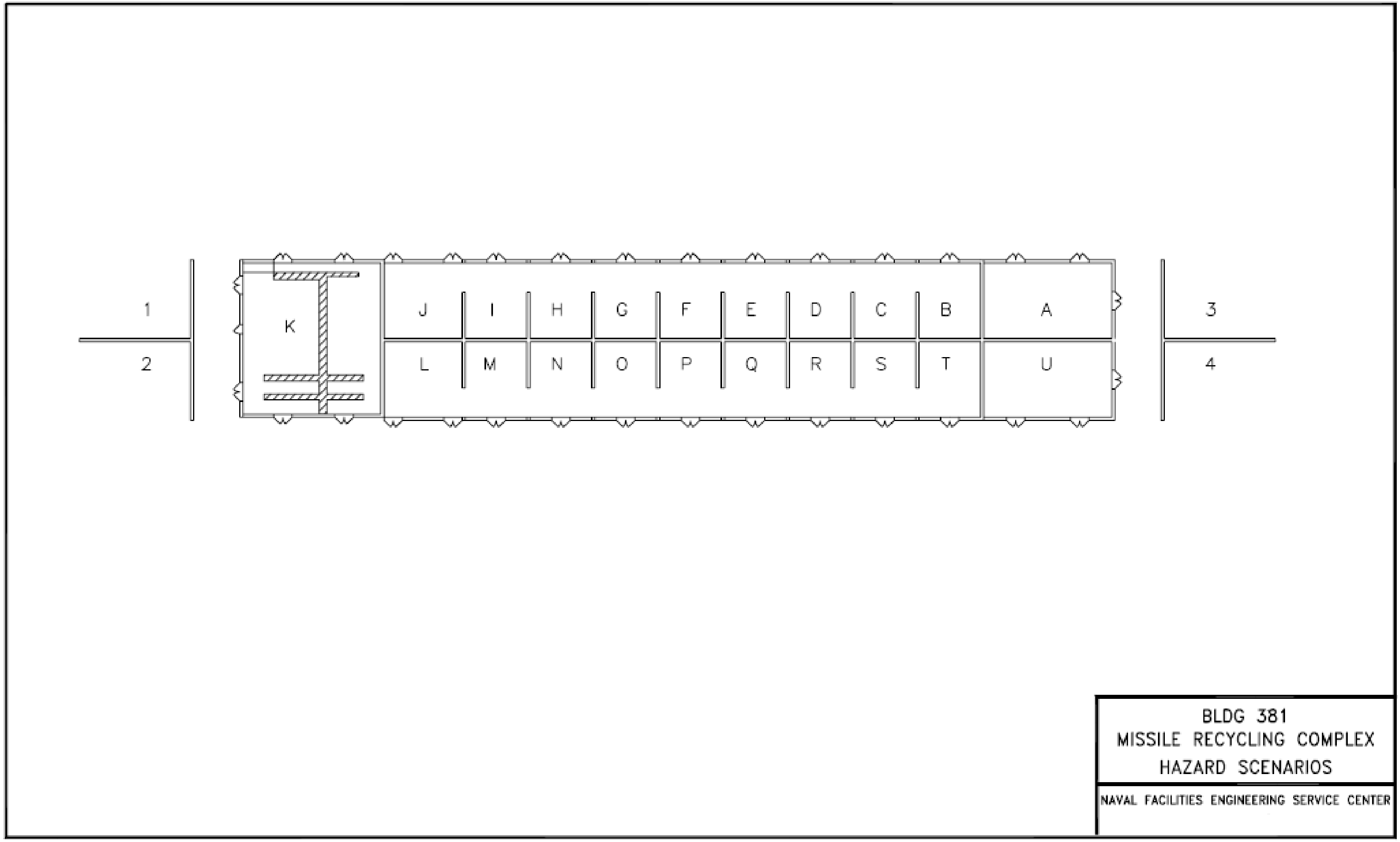

Figure 3-1. Plan view of Building 381 Missile Recycling Complex (MRC), Anniston Ammunition Depot.

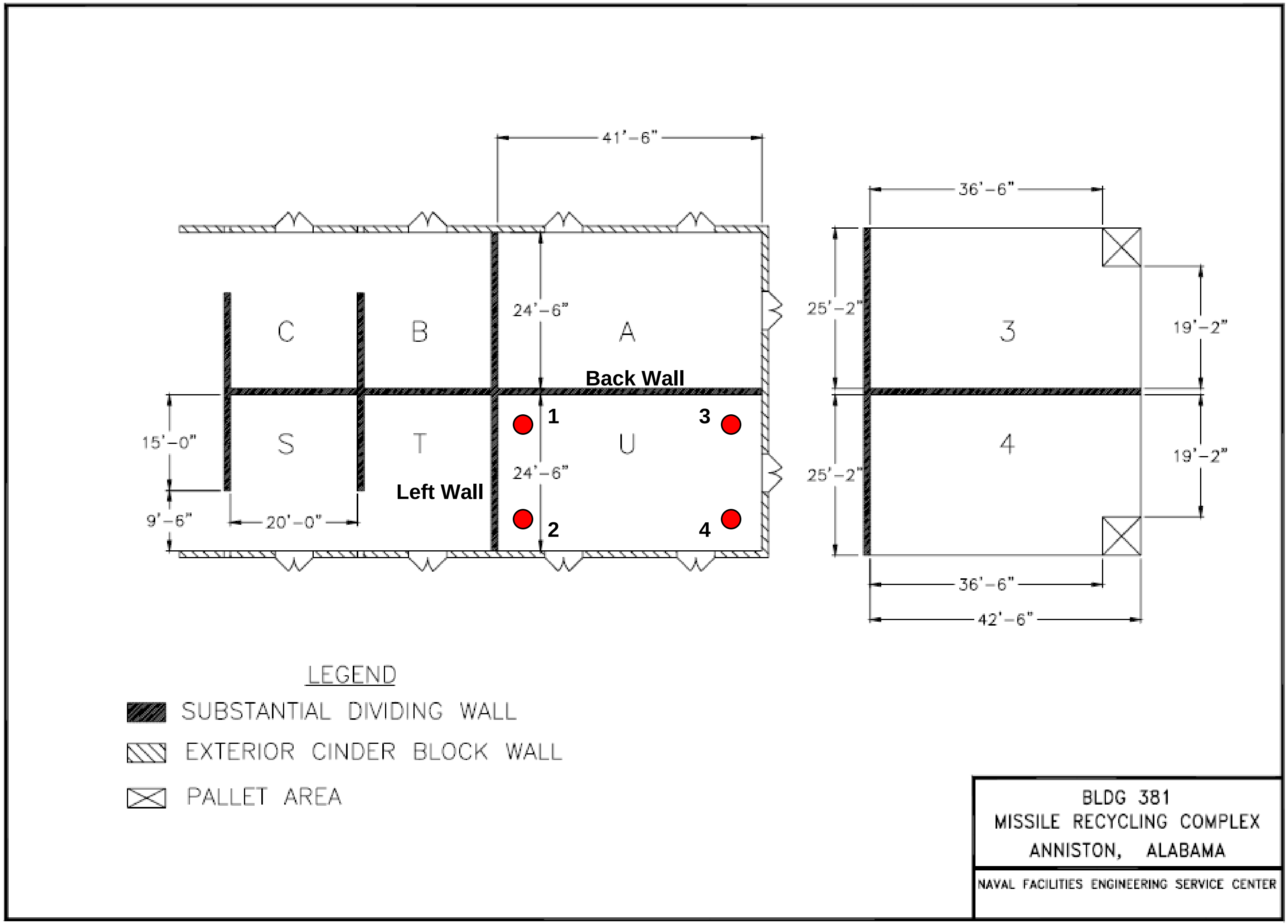

Figure 3-2. Plan view of Operating Bays C, S, B, T, A, U, 3 and 4.

3.1.2 Snow Load Effect

The Anniston MRC Building 381 bay U was evaluated for snow loads ranging from 0 lb/ft^2 to 40 lb/ft^2 and charge weights between 50 lbs and 425 lbs. The back and left SDWs were evaluated with the NEW located at the four points depicted in Figure 3-2. Calculations were performed following the procedure outlined in Section 2. For cases where breach did not occur, the wall velocity is used to determine if SD is prevented. For cases where breach did occur, the Impulse and Kinetic Energy are compared to the SD Threshold Criteria for Sensitivity Groups in Table 1-1. Points that exceed either the velocity, impulse or kinetic energy SD Threshold Criteria for SG4 are circled in red. At location 4 the velocity threshold is exceeded for NEWs of 425 lb and 400 lb with snow loads of 30 lbs/ft^2 and 40 lb/ft^2. Results of each scenario are presented in Figures 3-3 through 3-14.

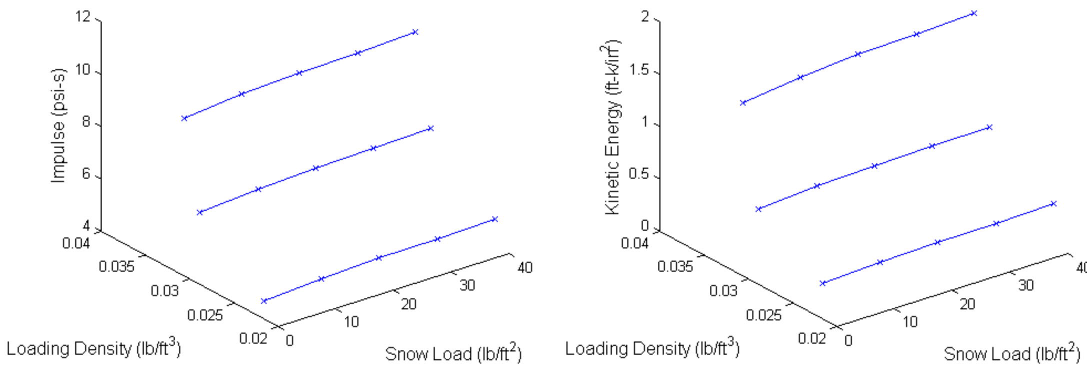

Figure 3-3. Impulse and Kinetic Energy versus Snow Load and NEW of the back wall at location 1 (Figure 3-2).

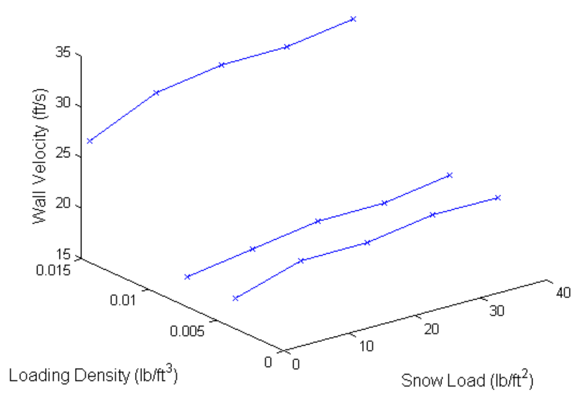

Figure 3-4. Velocity versus Snow Load and NEW of the back wall at location 1 (Figure 3-2).

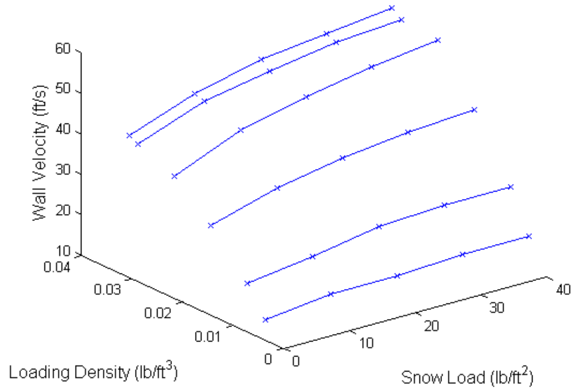

Figure 3-5. Velocity versus Snow Load and NEW of the back wall at location 2 (Figure 3-2).

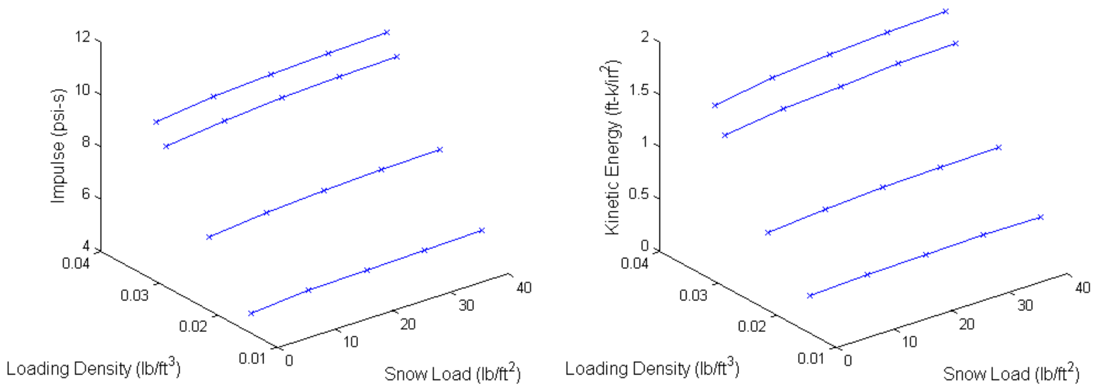

Figure 3-6. Impulse and Kinetic Energy versus Snow Load and NEW of the back wall at location 3 (Figure 3-2).

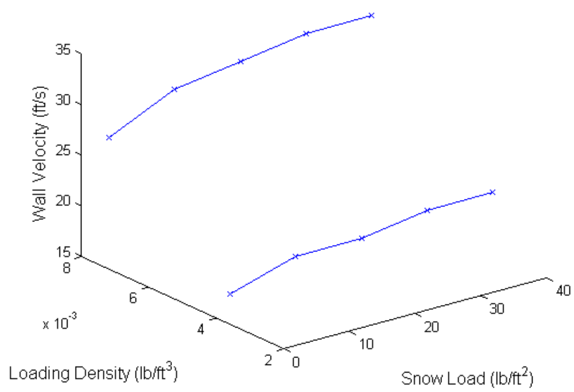

Figure 3-7. Velocity versus Snow Load and NEW of the back wall at location 3 (Figure 3-2).

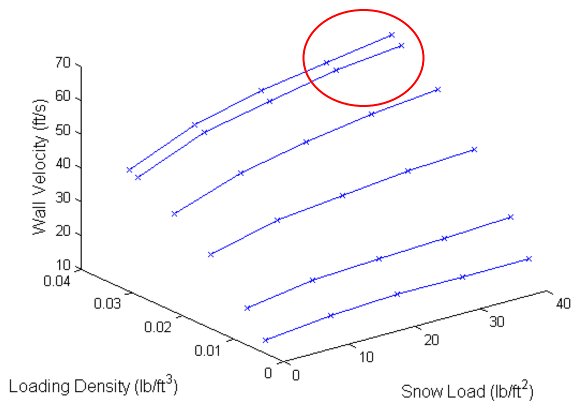

Figure 3-8. Velocity versus Snow Load and NEW of the back wall at location 4 (Figure 3-2).

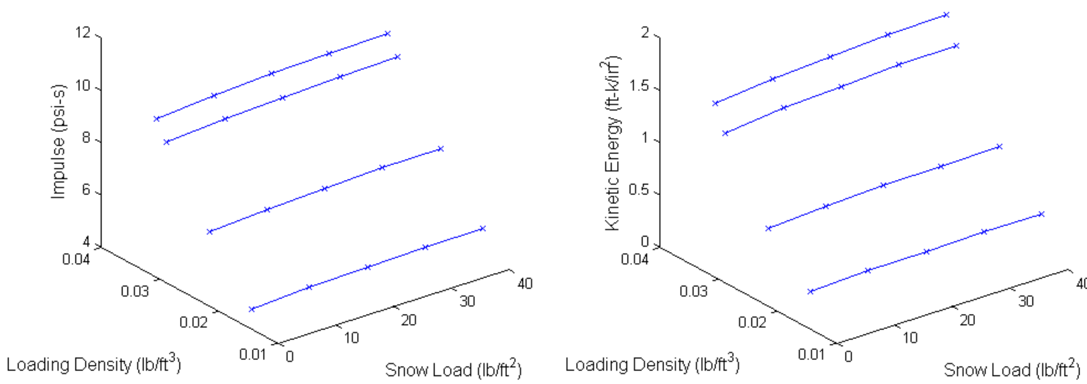

Figure 3-9. Impulse and Kinetic Energy versus Snow Load and NEW of the left wall at location 1 (Figure 3-2).

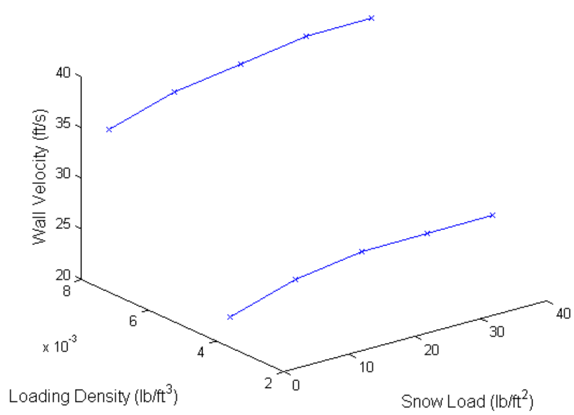

Figure 3-10. Velocity versus Snow Load and NEW of the left wall at location 1 (Figure 3-2).

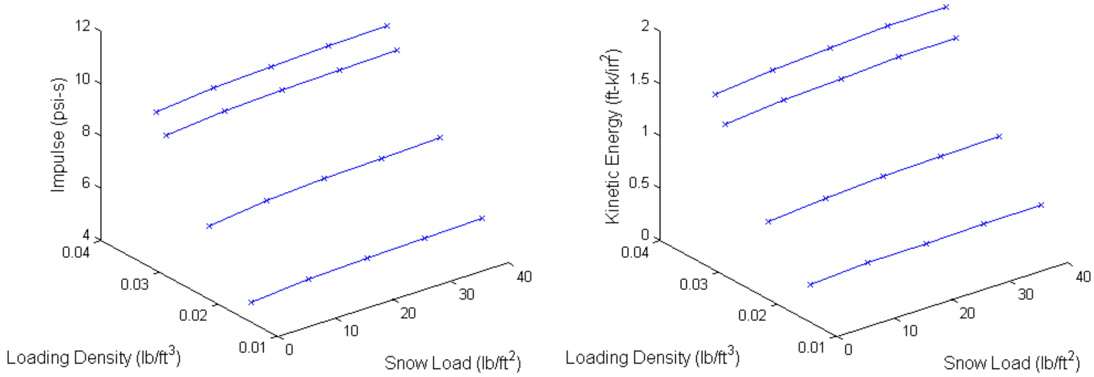

Figure 3-11. Impulse and Kinetic Energy versus Snow Load and NEW of the left wall at location 2 (Figure 3-2).

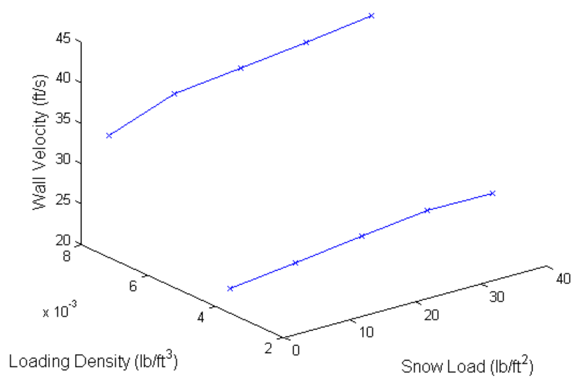

Figure 3-12. Velocity versus Snow Load and NEW of the left wall at location 2 (Figure 3-2).

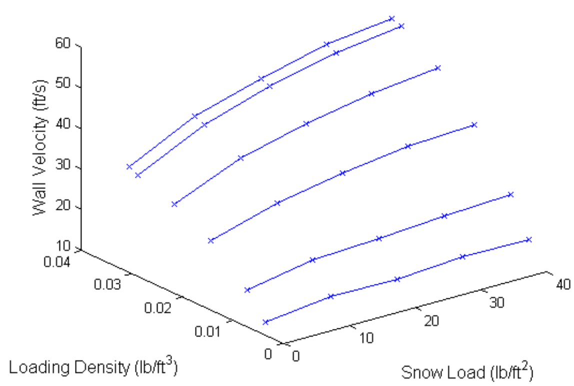

Figure 3-13. Velocity versus Snow Load and NEW of the left wall at location 3 (Figure 3-2).

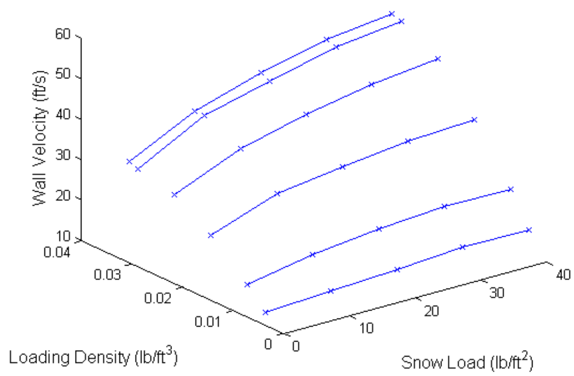

Figure 3-14. Velocity versus Snow Load and NEW of the left wall at location 4 (Figure 3-2).

3.2 HOLLOMAN AFB

3.2.1 Facility Description

The chosen magazine cube at Holloman AFB is 50-feet long x 30-feet wide x 20-feet high. The SDWs are 12-inches thick and have a weight of 150 lbs/ft^2. The configuration considered (Figure 3-13) has two parallel SDWs. The roof, front and rear wall of the magazine are 10 lbs/ft^2 corrugated steel classifying them as frangible. In all scenarios, the charge is located 6 feet away from the front frangible wall and the adjacent SDW at 3 feet off the ground. The charge is 24 feet away from the opposite SDW and 44 feet away from the rear wall at location 1. Only one location was calculated due to the symmetry of the magazine.

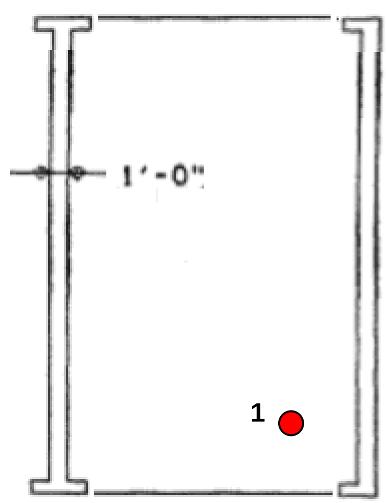

Figure 3-15. Plan view of 2-wall Holloman AFB magazine cube.

3.2.2 Snow Load Effect

The Holloman AFB storage cube was evaluated for snow loads ranging from 0 lb/ft^2 to 40 lb/ft^2 and charge weights between 50 lbs and 425 lbs. The close and far SDWs were evaluated with the NEW located at the point depicted in Figure 3-5. Calculations were performed following the procedure outlined in Section 2. For cases where breach did not occur, the wall velocity is used to determine if SD is prevented. For cases where breach did occur, the Impulse and Kinetic Energy are compared to the SD Threshold Criteria for Sensitivity Groups in Table 1-1. In all considered scenarios, the conditions to prevent SD are met. Results of each scenario are presented in Figures 3-6 through 3-18.

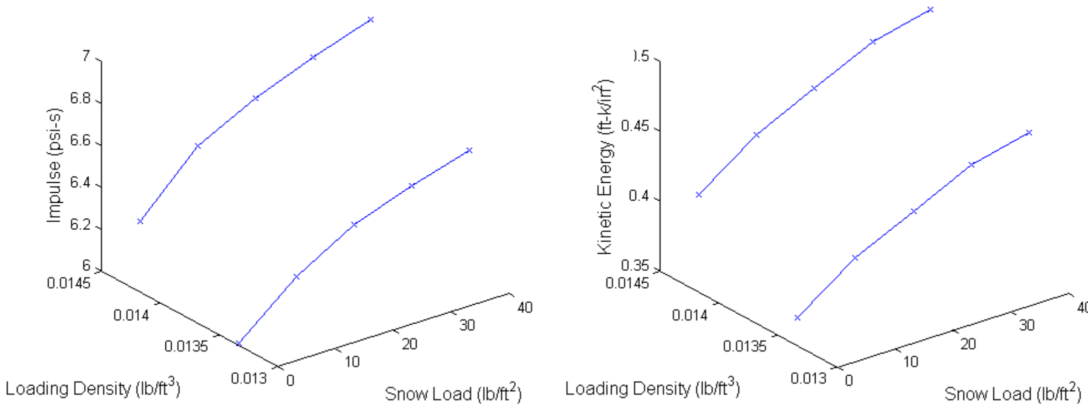

Figure 3-16. Impulse and Kinetic Energy versus Snow Load and NEW of the close wall.

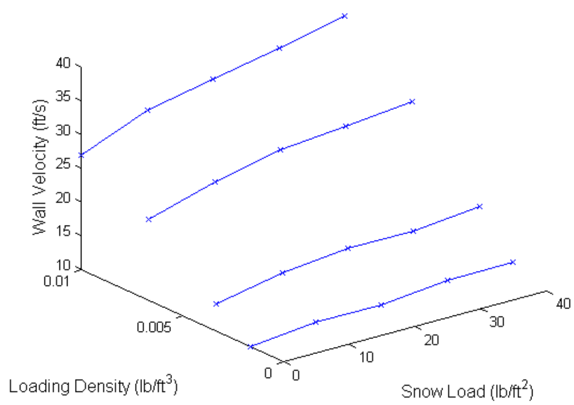

Figure 3-17. Velocity versus Snow Load and NEW of the close wall.

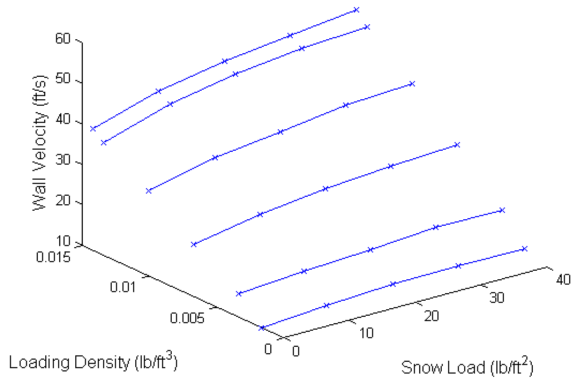

Figure 3-18. Velocity versus Snow Load and NEW of the far wall.

3.3 WHITEMAN AFB MULTI-CUBE

3.3.1 Facility Description

Figure 3-19 shows the plan of the Whiteman AFB multi-cube which consists of two parallel lines of storage cubicles separated by a continuous longitudinal dividing wall. The storage cubicles in a single row are separated by wing walls that are perpendicular to the longitudinal wall. The interior dimensions of each storage cubicle are 25-feet long by 12-feet wide by 10-feet tall. The SDWs are 12-inches thick and have a weight of 150 lbs/ft^2.

The physical properties of the wing and longitudinal SDWs satisfy criteria to be classified as substantial dividing walls.

The total interior volume of each storage cubicle is 3000 ft^2. For a maximum explosive weight of 425 lbs, the loading density is 0.141 lb/ft3 and is less than the maximum loading allowed by Reference 2.

Assuming the roof and the front wall of each storage cubicle are frangible surfaces, the scaled vent area is 1.92. This value exceeds the minimum value of 1.85 stated in Reference 2.

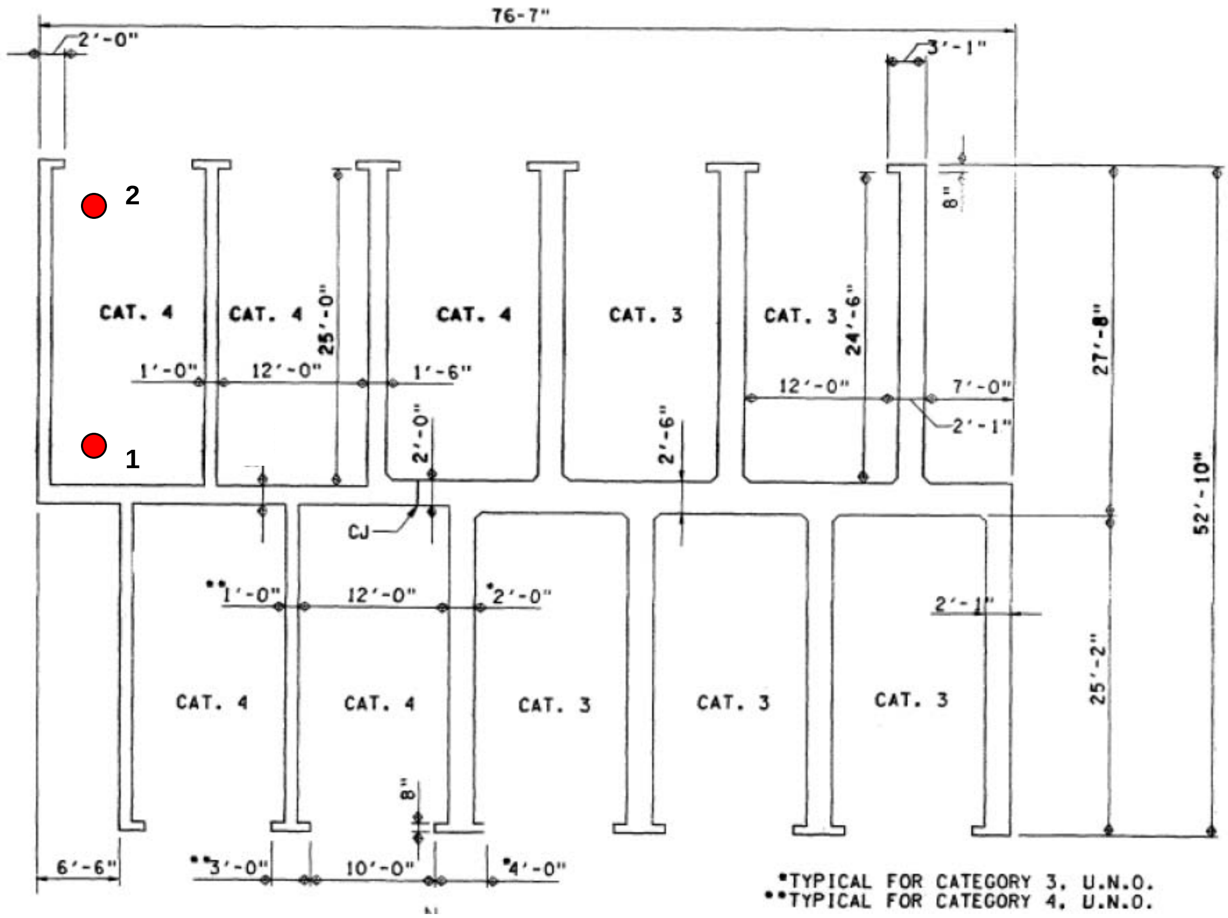

Figure 3-19. Plan view of Whiteman AFB multi-cube.

3.3.2 Snow Load Effect

The Whiteman AFB multi-cube was evaluated for snow loads ranging from 0 lb/ft^2 to 40 lb/ft^2 and charge weights between 50 lbs and 425 lbs. The left, right and back SDWs were evaluated with the NEW located at the two points depicted in Figure 3-17. Calculations were performed following the procedure outlined in Section 2. For cases where breach did not occur, the wall velocity is used to determine if SD is prevented. For cases where breach did occur, the Impulse and Kinetic Energy are compared to the SD Threshold Criteria for Sensitivity Groups in Table 1-1. Points that exceed either the velocity, impulse or kinetic energy SD Threshold Criteria for SG4 are circled in red. Results of each scenario are presented in Figures 3-20 through 3-30.

While the storage bay evaluated in this section satisfies the criteria of the SDW guidance, multiple scenarios were found, including for zero snow load, where the SD Threshold Criteria is exceeded and SD would not be prevented. In addition, at higher roof loads and NEW SD would not be prevented. The bay evaluated is narrow when compared to its length. This condition has the effect of creating very large load environments on the SDWs despite the low loading density.

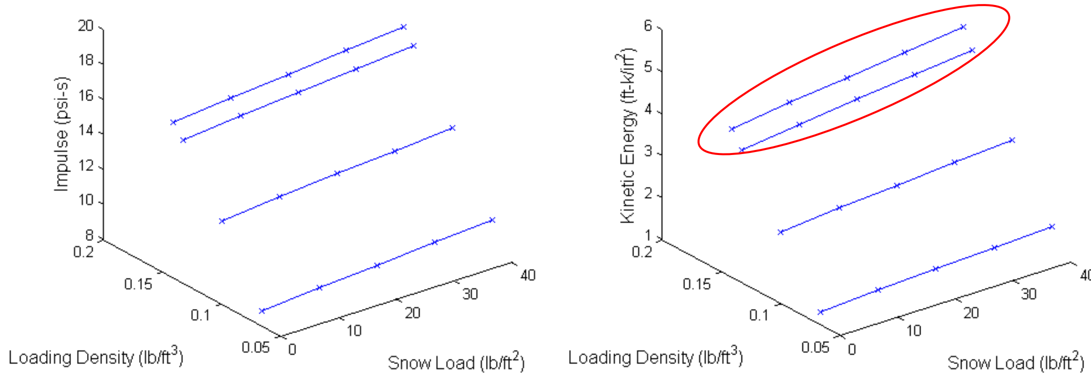

Figure 3-20. Impulse and Kinetic Energy versus Snow Load and NEW of the back wall at location 1 (Figure 3-19).

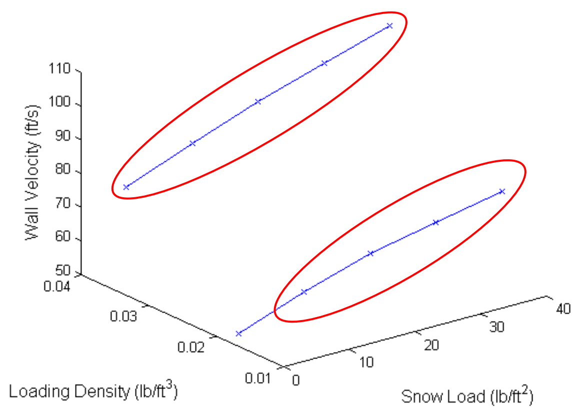

Figure 3-21. Velocity vs. Snow Load and NEW of the back wall at location 1 (Figure 3-19).

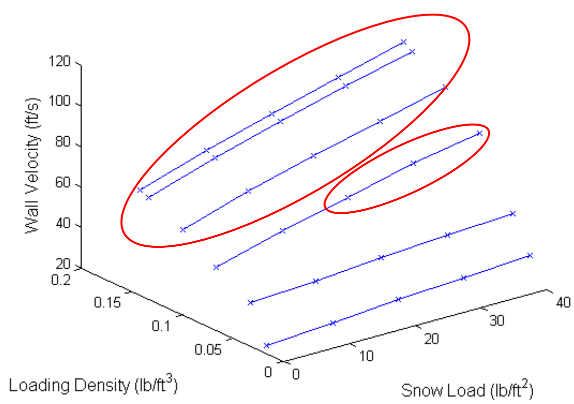

Figure 3-22. Velocity vs. Snow Load and NEW of the back wall at location 2 (Figure 3-19).

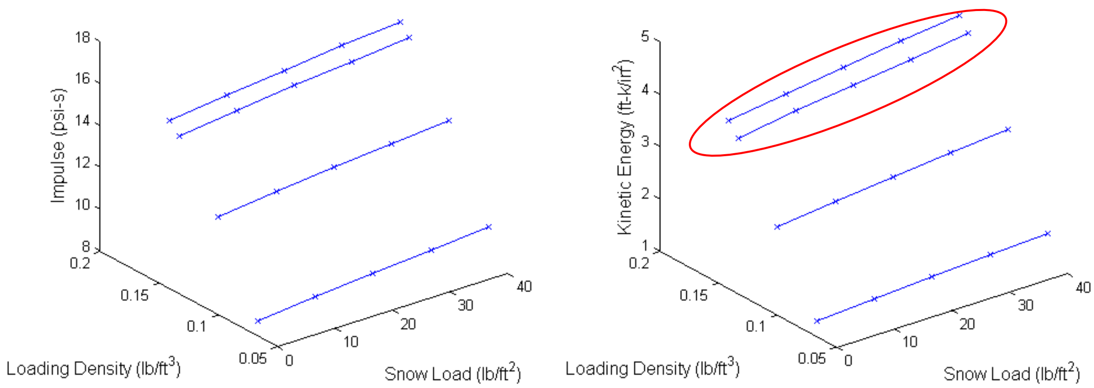

Figure 3-23. Impulse and Kinetic Energy versus Snow Load and NEW of the close wall at location 1 (Figure 3-19).

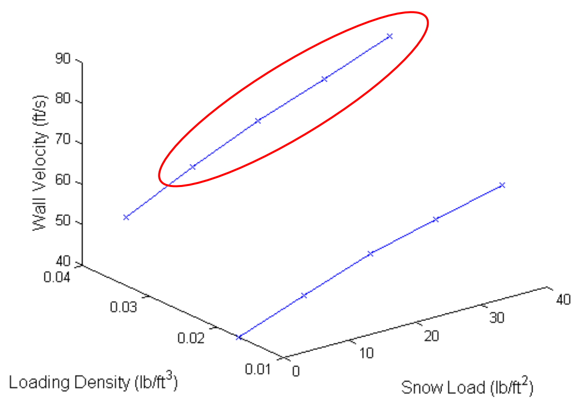

Figure 3-24. Velocity vs. Snow Load and NEW of the close wall at location 1 (Figure 3-19).

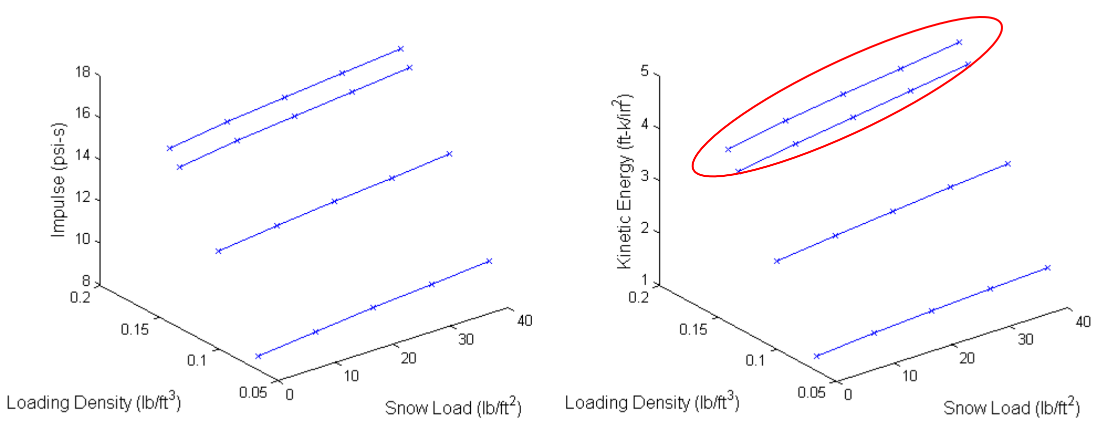

Figure 3-25. Impulse and Kinetic Energy versus Snow Load and NEW of the close wall at location 2 (Figure 3-19).

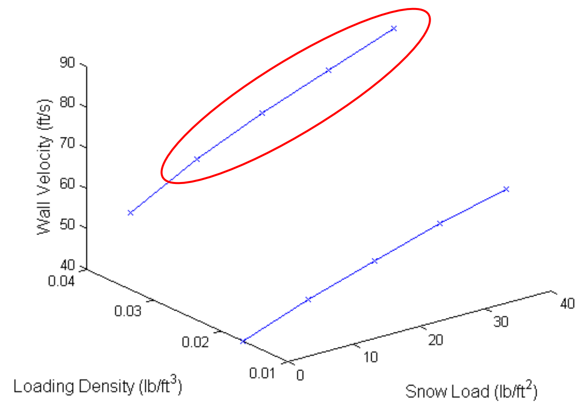

Figure 3-26. Velocity vs. Snow Load and NEW of the close wall at location 2 (Figure 3-19).

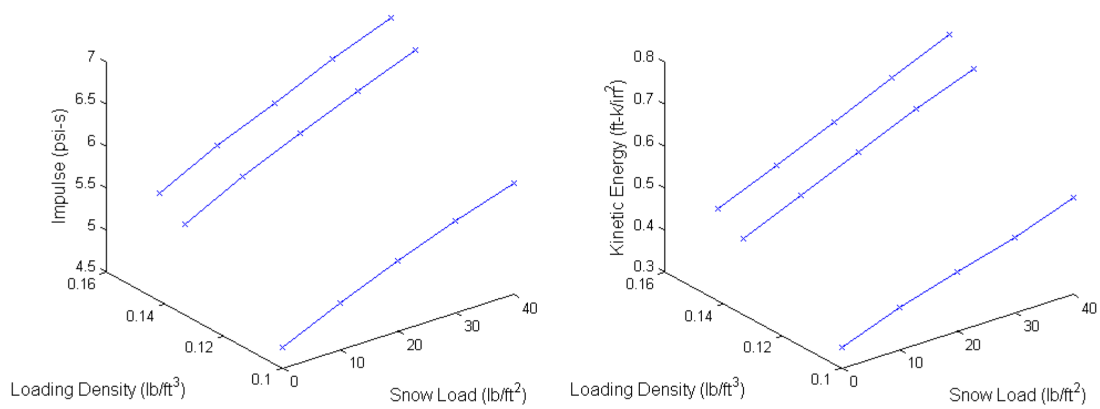

Figure 3-27. Impulse and Kinetic Energy versus Snow Load and NEW of the far wall at location 1 (Figure 3-19).

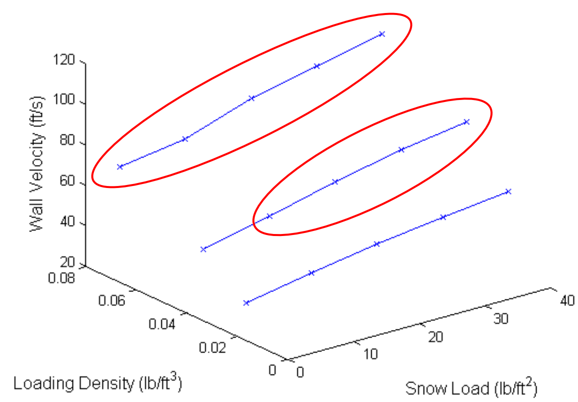

Figure 3-28. Velocity vs. Snow Load and NEW of the far wall at location 1 (Figure 3-19).

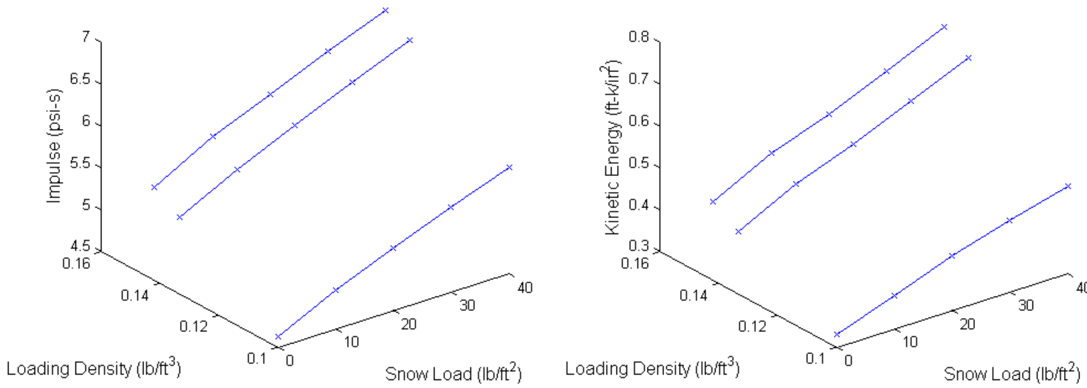

Figure 3-29. Impulse and Kinetic Energy versus Snow Load and NEW of the far wall at location 2 (Figure 3-19).

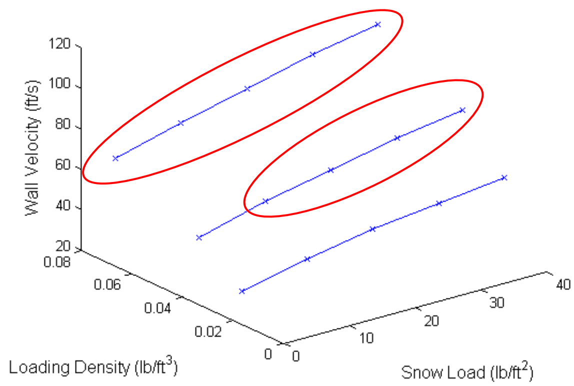

Figure 3-30. Velocity vs. Snow Load and NEW of the far wall at location 2 (Figure 3-19).

4.0 CONCLUSION

This paper provides a procedure for evaluating the effectiveness of SDWs. The effect of increased roof loading has been illustrated using representative facilities at Anniston Ammunition Depot, Holloman AFB and Whiteman AFB.

The evaluation of the Whiteman AFB multi-cube illustrates a problem with the current SDW memo (Ref. 6). It has been observed that for situations that are close to the loading density limit and have large length to width ratios, the SD Threshold Criteria for SG4 can be exceed and SD would not be prevented.

5.0 REFERENCES

1. “Explosives Safety Standards”, Air Force Manual 91-201, May 1999
2. “Performance Criteria For 12-Inch Concrete Substantial Dividing Walls,” Lahoud, Paul, Zehrt, William, Acosta, Patrick, U.S. Army Engineer Division Huntsville, July 1995.
3. E-Mail from Eric Deschambault (DOD Explosives Safety Board) to Kevin Hager (NAVFAC ESC) “FW: Flaked TNT question for Eric”, dated July 16, 2008 12:12 pm.
4. "SHOCK User's Manual", Anonymous, Version 1.0, Naval Civil Engineering Laboratory, Port Hueneme, CA, January 1988
5. “High Performance Magazine Non-Propagation Wall Design Criteria”, Technical Report TR-2112-SHR, Hager, Tancreto, Swisdak, Naval Facilities Engineering Service Center, June 2002.
6. “DDESB Memorandum of 15 January 2003, Subject: Guidance on 12-inch Thick Substantial Dividing Walls”, Department of Defense Explosives Safety Board, Alexandria, VA, January 2003
7. Wager, Philip, Connett, Joseph, “FRANG User’s Manual”, Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1989.

Naval Facilities Engineering Service Center

Effect of Roof Load on Substantial Dividing Wall (SDW) Protection

2010 DoD Explosive Safety Board Seminar

Presented by:
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Research Structural Engineer
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13 July 2010

Substantial Dividing Walls (SDW)

- Reinforced concrete dividing walls separate ordinance groupings
- Used to subdivide explosives for quantity-distance definition allowing siting to be based on NEW of single bay

- **Problem:**
  - Increased roof loading (including snow loads) increases blast pressures and can result in failure of the SDW to prevent sympathetic detonation

Current SDW Guidance: Walls

- A minimum thickness of 12 inches is required.
- Steel reinforcing bars (rebar) are located on both faces of the wall.
- The minimum size of the vertical and horizontal rebar is ½-in diameter.
- Vertical and horizontal rebar are spaced not more than 12-in apart.
- Position of bars on one face staggered with the bars on opposite face
- Concrete cover over the steel reinforcing bars is approximately 2-in.
- The minimum concrete compressive strength is 2,500 psi.
- SDW main steel is continuous into the supports.

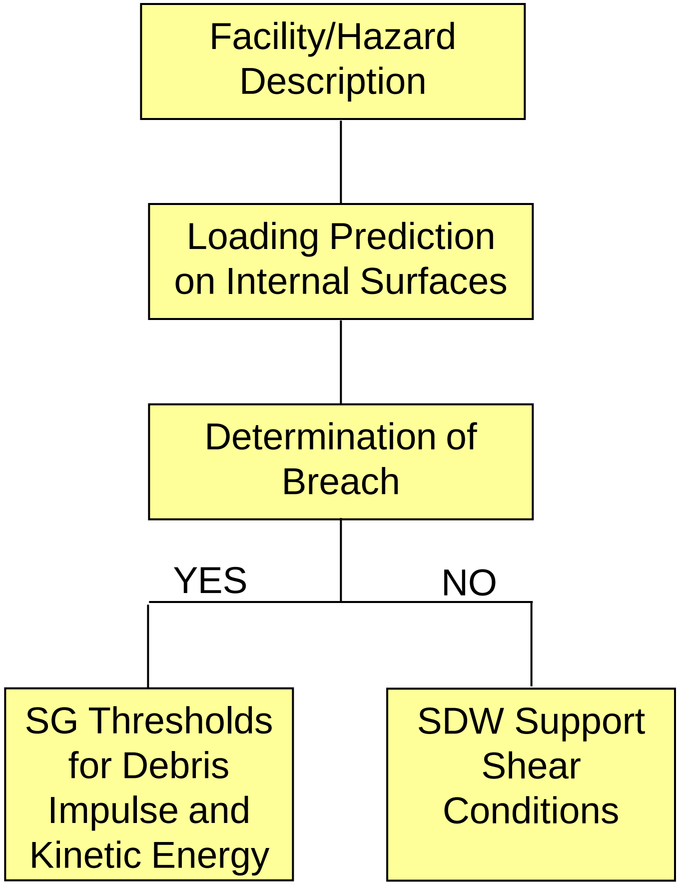
“DDESB Memorandum of 15 January 2003, Subject: Guidance on 12-inch Thick Substantial Dividing Walls”, Department of Defense Explosives Safety Board, Alexandria, VA, January 2003

Current SDW Guidance: Facility

- The Maximum Credible Event (MCE) is limited to 425 lbs Net Explosive Weight (NEW).
- The minimum separation distance from any wall to any explosive donor is 3-feet.
- The loading density (Net Explosive Weight / room's internal volume) is less than 0.20 lb/ft^3 for Sensitivity Groups (SGs) 1 through 4.
- The minimum scaled vent area ($A/V^{2/3}$) for the cubicle is 1.85. A is defined as the total uncovered and covered area for venting blast pressures. V is defined as the internal volume of the cubicle.
- **The maximum unit weight of any frangible surface (such as the roof and a wall) is 10 lb/ft^2.**

"DDESB Memorandum of 15 January 2003, Subject: Guidance on 12-inch Thick Substantial Dividing Walls", Department of Defense Explosives Safety Board, Alexandria, VA, January 2003

Determination of SDW Effectiveness



- Three representative facilities are presented:
  - –Anniston Ammunition Depot Building 381 Missile Recycling Complex (MRC)
  - –Holloman AFB multi-cube
  - –Whiteman AFB multi-cube

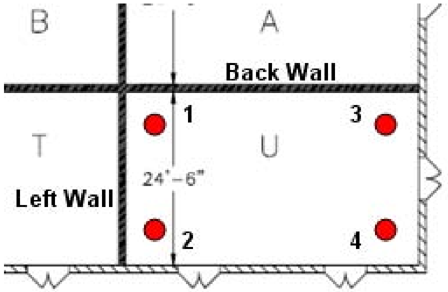
Sympathetic Detonation (SD) Criteria

- Sensitivity Groups (SG) are used to classify ordnance by its sensitivity to crushing by secondary debris from non-propagation walls
  - –SG1: Robust Munitions
  - –SG2: Non-Robust Munitions
  - –SG3: Fragmenting Munitions
  - –SG4: Cluster Bombs/Dispenser Munitions
  - –SG5: SD Sensitive Munitions
- If the calculated momentum and kinetic energy of the secondary debris from SDWs are less than the thresholds, detonation of ordnance due to crushing is not expected.

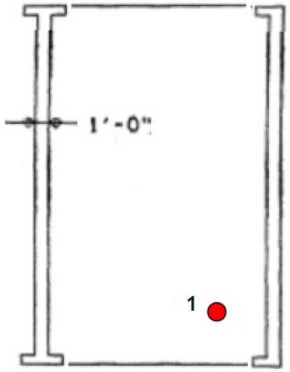
HP Magazine Sensitivity Groups		Unit Impulse and Energy Loads	
Group No.	Group Description	Impulse, I_{thres} (psi-sec)	Energy, KE_{thres} (ft-k/in^2)
1	Robust	45	24.5
2	Non-Robust	67	24.5
3	Fragmenting	53	8.49
4	Cluster Bombs/ Dispenser Munitions	25.6	3.77
5	SD Sensitive	5.23	0.3

Representative Facilities

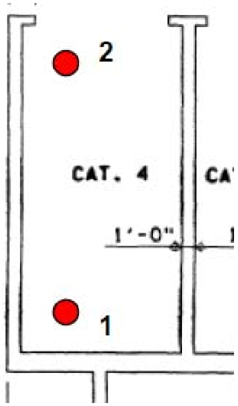
- Anniston Ammunition Depot Missile Recycling Complex



- Holloman AFB multi-cube



- Whiteman AFB multi-cube



  - Large individual bay
  - Large scaled vent area

  - Drive through facility

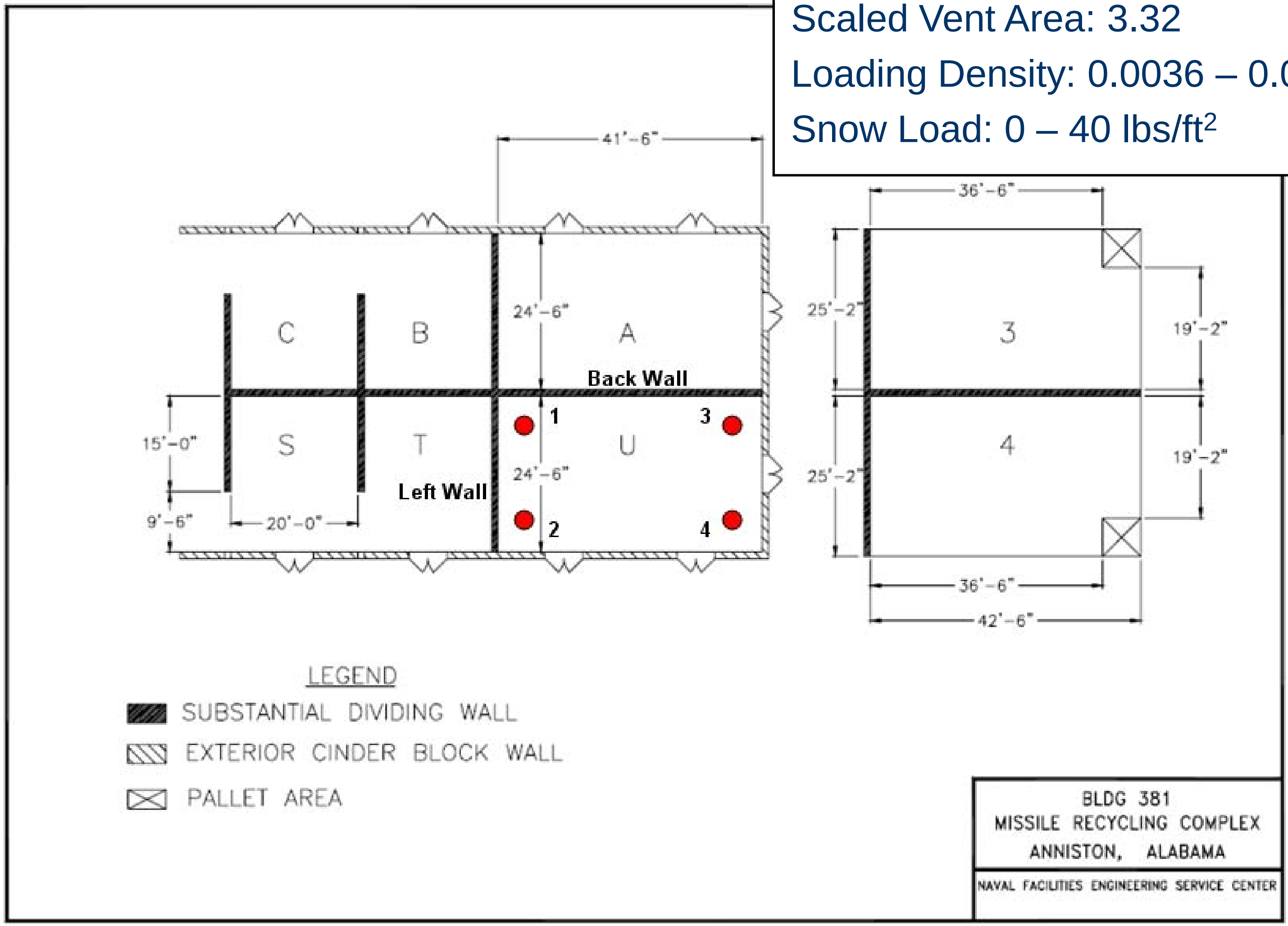
  - Larger length to thickness ratio
  - Closer to loading density and vent area limits

Anniston Ammunition Depot Building Details

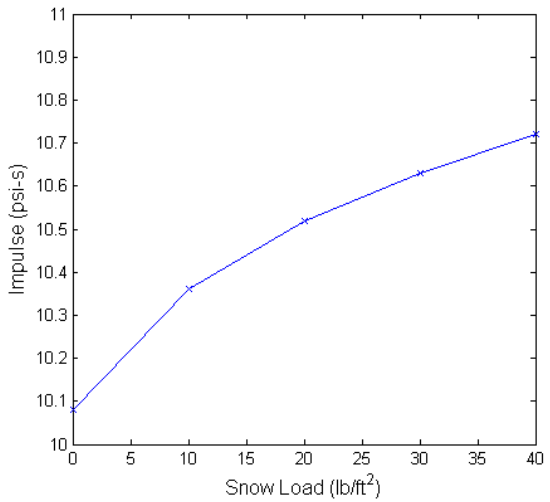
Scaled Vent Area: 3.32

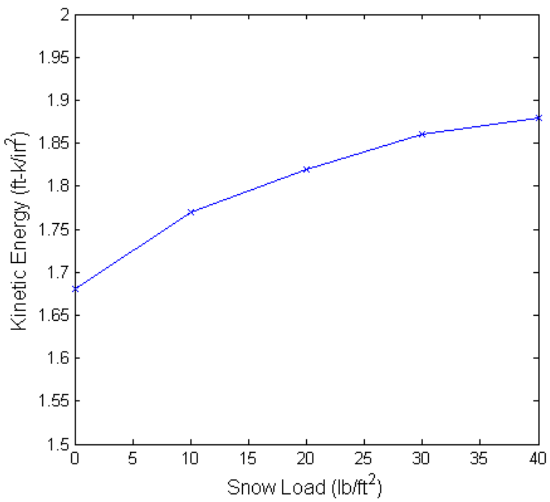
Loading Density: 0.0036 – 0.031 lb/ft^3

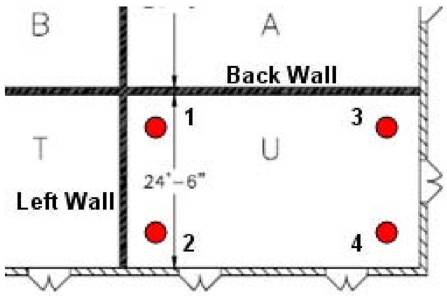
Snow Load: 0 – 40 lbs/ft^2



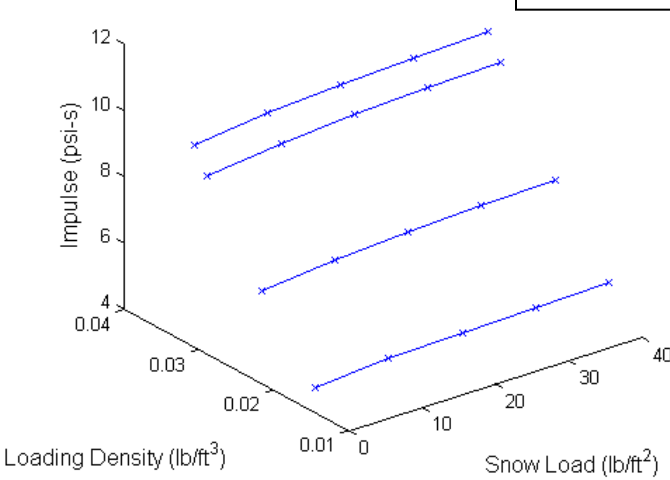
Anniston Ammunition Depot Building Results

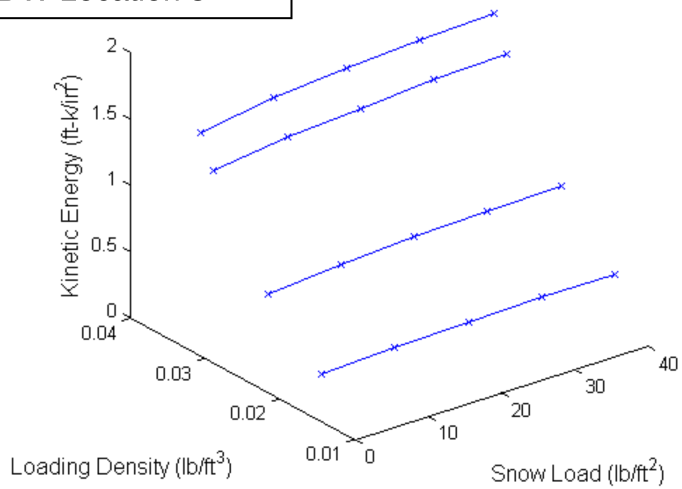






Back SDW Location 3



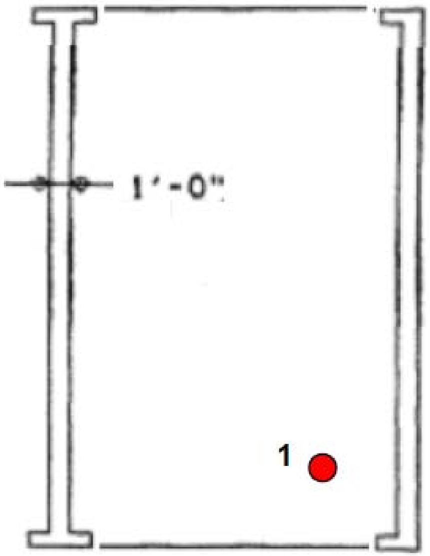


Holloman AFB Multi-cube Building Details

Scaled Vent Area: 2.80

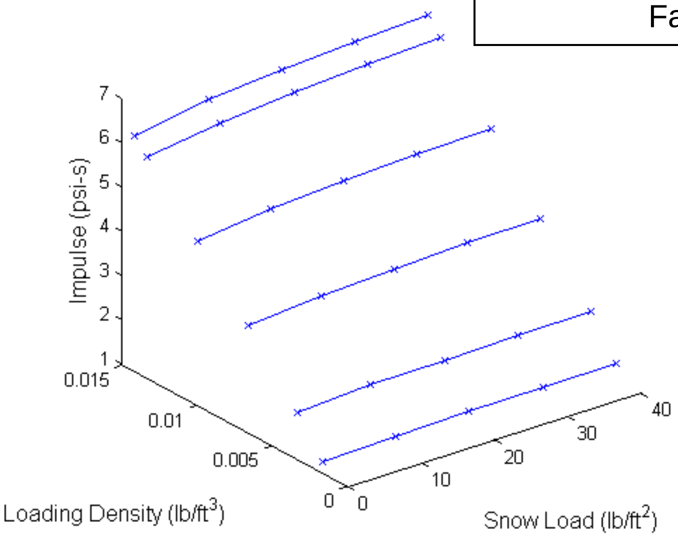
Loading Density: 0.0017 – 0.014 lb/ft^3

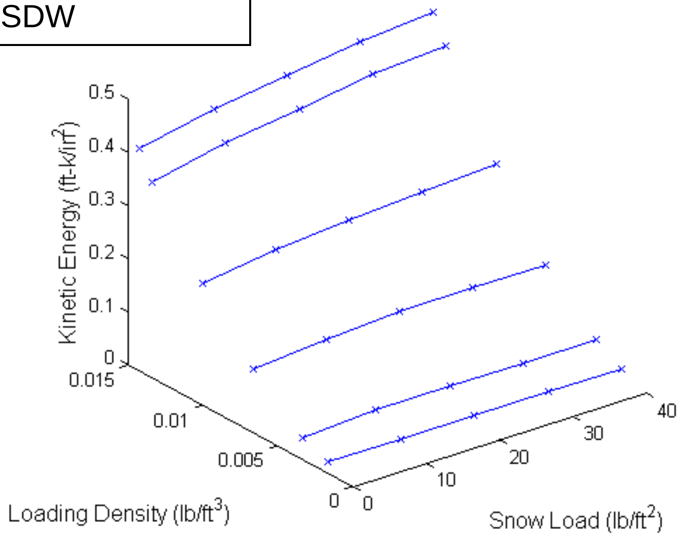
Snow Load: 0 – 40 lbs/ft^2



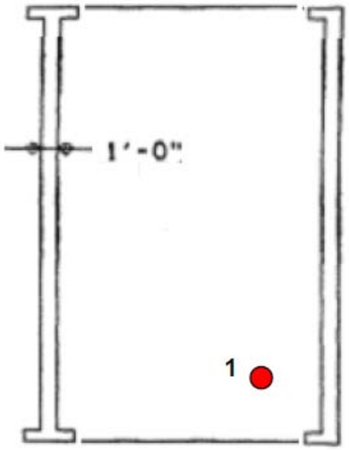
Holloman AFB Multi-cube Results

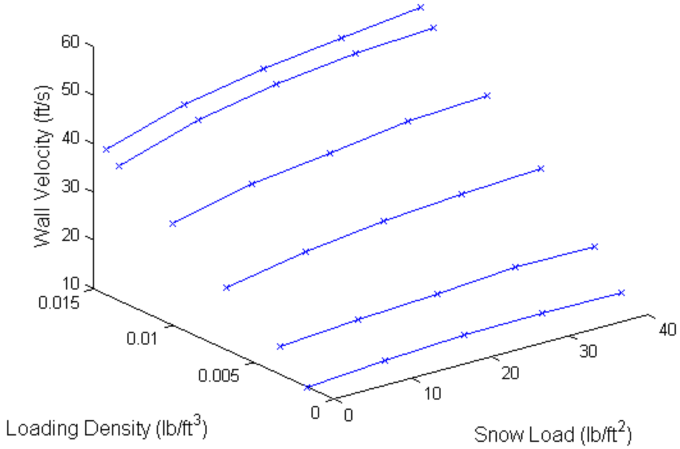
Far SDW





Close SDW



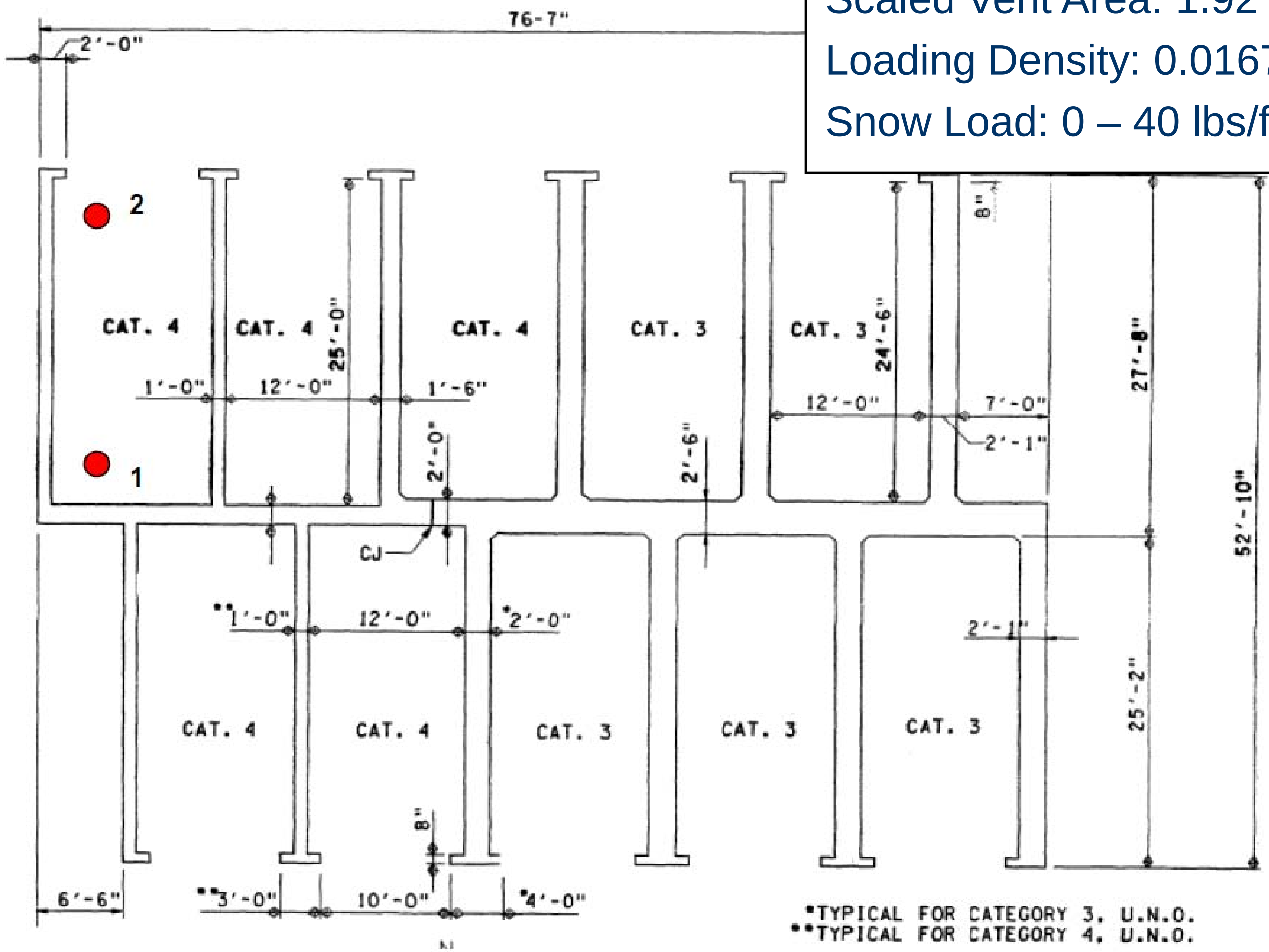


Whiteman AFB Multi-cube

Scaled Vent Area: 1.92

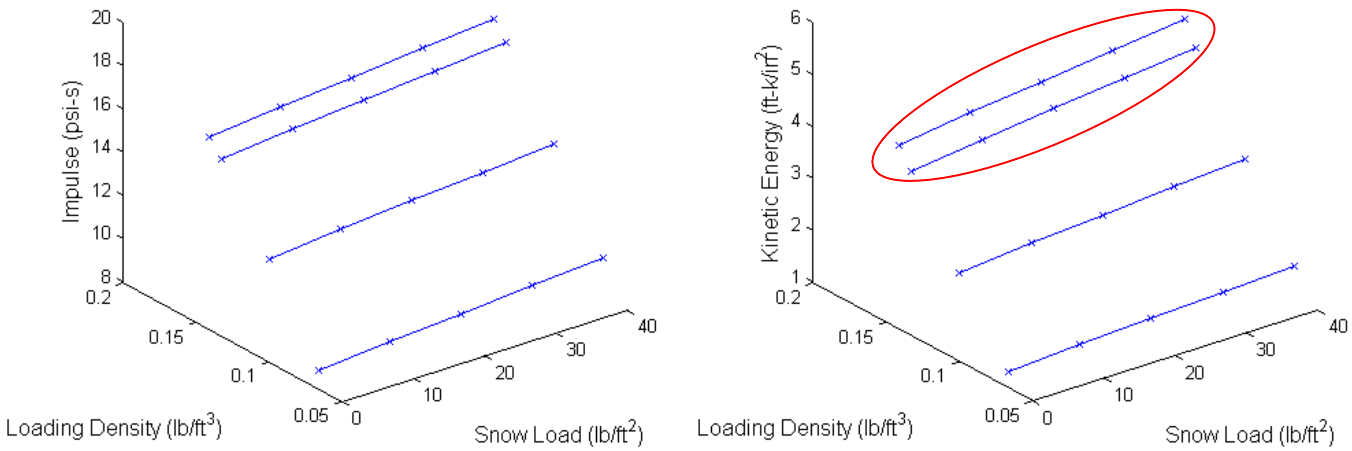
Loading Density: 0.0167 – 0.142 lb/ft^3

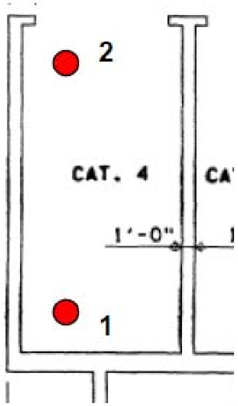
Snow Load: 0 – 40 lbs/ft^2



Whiteman AFB Multi-cube Results

Back SDW Location 1





- At larger loading density wall debris kinetic energy exceeds SD thresholds for SG 4, even at zero snow load.
- This is observed in facilities with large length to width ratios:
  - –Whiteman: L/W = 2.08
  - –Anniston: L/W = 1.69
  - –Holloman L/W = 1.67

Conclusions

- In cases where roof load exceeds 10 lbs/ft^2 the outlined procedure must be followed to obtain NEW limits
- Curves to predict reduced NEW limits with roof load can be generated
- Effect of even large snow loads remain small except near loading density and scaled vent area limits
- A problem was identified in the current guidance for facilities with large length to width ratios
- A limitation on length to width of facilities may need to be implemented for facilities operating near loading density limits